Evaluation and indirect estimation of nitrate losses from the agricultural microbasin Rybárik

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Abstract The long-term trends of mean monthly nitrate concentrations in stream and drainage runoff were evaluated in the experimental microbasin Rybárik (0.119 km^2) at the Institute of Hydrology, Slovak Academy of Sciences, during the period 1987–2005. The results of analyses indicate a decreasing trend of nitrate concentration after the year 1989, but with relatively high losses in some years and relatively low losses in other years. This decreasing trend is mainly caused by a decrease in the use of nitrogen fertilizers. The nitrate concentration in surface runoff strongly correlates with runoff and fertilization. Based on measured data, an empirical relation was found describing the dependence of annual nitrate transport in the stream on annual runoff depth and on the annual amount of applied nitrogen fertilizers.

Key words: *Nitrate, Nitrate losses, Experimental microbasin, Nitrogen fertilizers*

Introduction

Nitrate (NO_3^-) is the final oxidation product of the most nitrogen compounds. Nitrate is present in atmospheric aerosol, rainfall, surface water, and ground water (Fľaková et al., 1997). The main sources of inorganic nitrogen components in surface water are geological sources, mineralisation of organic matter and agriculture (artificial and natural fertilizers), sewage water and polluted rainfall (NO_x emissions from combustion processes and automobile transport).

At present, water quality research in agricultural catchments focuses on transport of inorganic nitrogen forms from the surface - unsaturated zone - groundwater system to the streams (Thornton & Dise, 1998; Haggard et al., 2003; Schilling & Zhang, 2004; Haraldsen & Stalnacke, 2006.). The chemical composition of stream water is a function of the hydrobiogeochemical processes in the basin. These processes show significant seasonality (Moldan et al., 1994). The problem of transport of soluble and insoluble compounds to the streams is further complicated by human activities that influence the natural processes and modify the abundance of particular elements in the ecosystem (Lenhart et al., 2003; Zhang & Schilling, 2006; Fišák et al., 2006).

Raczak and Zelazny (2005) monitored changes of inorganic nitrogen forms during twelve 24-hours discharge situations in the Stara Rzeka catchment in Poland. In the forested part of the catchment (41%) there were no significant concentration changes during the day. The chemical composition instability level increased with increasing of anthropogenic influences in the catchment (59% agricultural use). Fottova (1992) elaborated chemical data from rainfall and runoff in the small basins in the former Czechoslovakia (small basins network – Geomon). Interesting is a comparison of forested and agricultural basins. In general there is a higher load of the most chemical compounds from agricultural basins than from forested. This growth is more apparent in the worst buffered basins with relatively lower alkalinity on the crystalline basement, whereas in flysch basins is agricultural production buffered by weathering of bedrock.

Pekárová & Miklánek (2005) and Pekárová et al. (1999) showed the development of nitrate concentrations in the Mošteník basin (Slovakia), and the nitrogen balance and modelling of its agricultural subbasin, Rybárik, and forested subbasin, Lesný, during the period 1988–1992. The water quality in Slovak experimental microbasins (Mošteník, Ondava and Jalovecky brook), nitrate concentrations, their trends and losses between 1986 and 2005 were evaluated by Pekárová & Pekár (1996), Halmová (1996), Holko et al. (2004, 2006), and Lichner et al. (1999).

The topic of this study is the analysis of nitrate concentrations in stream and drainage water, evaluation of their seasonal changes and trends and annual nitrate losses from the 90% agricultural experimental microbasin Rybárik in the period of 1987–2005.

Methodology

Basin description

The experimental basin Mošteník (17.2 km^2) of IH SAS near Považská Bystrica city was established in 1958. The Mošteník basin was divided into eight sub basins, each with a different land use (e.g agricultural - Rybárik, forested – Lesný).

Total area of the Rybárik basin (Fig. 1) is 0.119 km^2. The length of the stream from spring to closing profile is 256 m, the mean slope of the stream is 9.1%, and the mean slope of the basin is 14.9%. The elevation is from 369 to 434 m above sea level. The mean annual precipitation is 738 mm, the runoff 231 mm (years 1965–2004); the mean annual air temperature is 8.1^{o}C. Geological conditions in the Rybárik basin are characterized by flysch substrates (alternating layers of clay and sandstone). The basin is 70% cultivated by the state farm, private farmer covers the rest of the area.

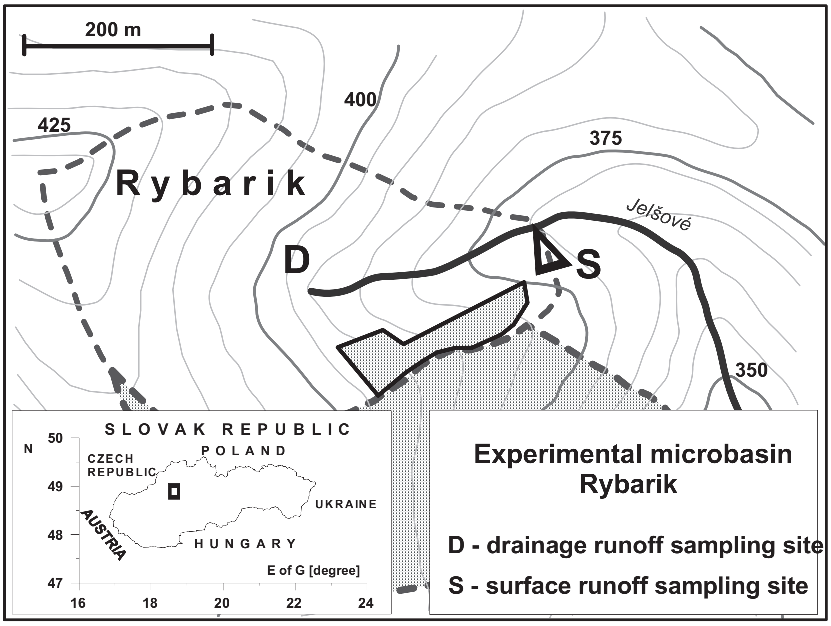

Fig. 1. Experimental microbasin Rybarik with drainage runoff sampling site (D) and surface runoff sampling site (S)

Sampling and measurement methodology

In the Rybárik basin, stream runoff is measured by the Thomson weirs (large – 90^o and small – 45^o), and recorded continuously by limnigraph (Photo 1). Since 1987, stream and drainage water samples were taken in 1-3 day intervals, depending on the runoff change (Photo 2). Approximately 100 samples per year were taken from both localities. Some of the indicators were measured in the field (pH, electric conductivity, water temperature), and chemical analyses were made in a certified laboratory to determine qualitative parameters (NO_3^-, NO_2^-, NH_4^+ and PO_4^{3-} concentrations).

Fertilization

Agriculture and the use of artificial nitrogen fertilizers is the main anthropogenic source of nitrate in the Rybárik microbasin. The amounts of nitrogen fertilizers used in Slovakia since 1950 are displayed in Figure 2. Fertilization rates were highest (around 90 kg of nitrogen per 1 ha of agricultural land) between 1970 and 1990. A rapid decrease in the use of nitrogen fertilizers in Slovakia took place after the year 1989, a phenomenon related to economical changes, a decrease in agricultural production, increasing expenses and a decrease in the number of farm animals.

Photo 1. Water quality sampling - small Thomson weir, Rybárik basin (Pekárová, May, 2005).

Photo 2. Water quality sampling – drainage water, Rybárik basin (Pekárová, April, 2006).

Lexa & Kvítek (2003) found that a similarly rapid decrease of nitrogen fertilizer use in Czechia after 1990 stopped further water quality degradation but did not contribute to water quality improvement. In Figure 2, the decreasing trend in usage of nitrogen fertilizers in the Rybárik microbasin after 1989 is evident. With small variations, it copies the nitrogen fertilizer usage trend seen in Slovakia. In the year 2005, no nitrogen fertilizers were applied in the microbasin. Crops grown in the agricultural microbasin Rybárik are listed in Table 1, along with the amounts of nitrogen fertilizers applied, obtained from the local state farm and a private farmer. The sequence of crops does not respect the established rules of crop rotation. The crops with the potential to enrich the soil with organic matter are missing (Koníček & Stančík, 2002).

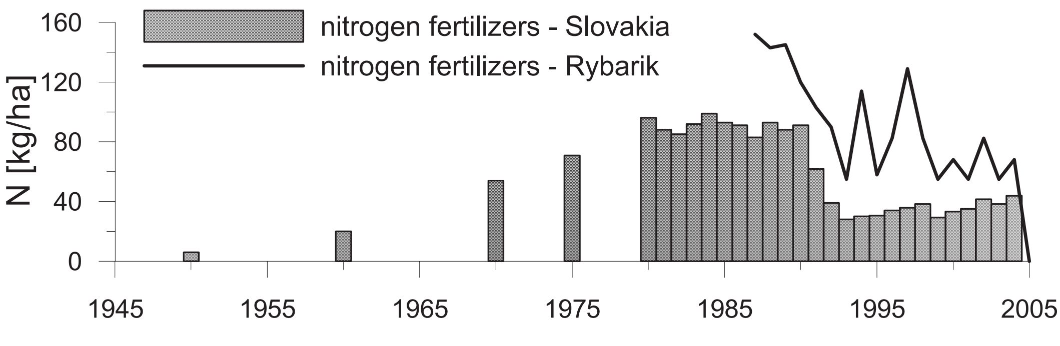

Fig. 2. Annual nitrogen fertilizer amounts used from 1950 to 2005 in Slovakia (in kg N/ha of agriculture land) and in the Rybárik microbasin from 1987 to 2005 (in the period 1950–1980, data was available only in years 1950, 1960, 1970, and 1975)

Table 1. Annual runoff depth (Ra) in [mm], crops (S – spring, A – autumn) and mineral nitrogen fertilization [$kgN.ha^{-1}$] in the Rybárik basin between 1987–2005.

Year	R_a	Crops - S	Crops - A	MN	Year	R_a	Crops - S	Crops - A	MN
1987	285	Maize		152	1997	176	Wheat		129
1988	216	Maize		143	1998	172	Barley	Mustard	83
1989	138	Barley	Wheat	145	1999	175	Mustard	Wheat	55
1990	163	Wheat		120	2000	193	Wheat		68
1991	114	Oil rape		103	2001	273	Maize	Wheat	55
1992	223	Maize	Rye	90	2002	336	Wheat	Oil rape	83
1993	136	Rye		55	2003	182	Maize		55
1994	299	Maize	Wheat	114	2004	172	Oat	Clover	68
1995	196	Wheat	Oil rape	58	2005	241	Clover	Clover	0
1996	175	Colza	Wheat	83					

Results and discussion

Nitrate concentrations in stream and drainage water

Arithmetic averages of actual nitrate concentrations were made to produce mean monthly nitrate concentrations in stream water (S) and drainage water (D). These are displayed in Figure 3, which shows a distinct decreasing trend of nitrate concentrations in both the stream water and the drainage water, corresponding to the decreasing trend in nitrogen fertilizer applications in the Rybárik microbasin.

As Figure 4 shows, the maximum nitrate concentrations in both surface water and drainage water occur in spring – during the period of snow melt, when there is no vegetation cover on arable lands, the runoff rapidly increases and nitrates leach from the upper layer of the soil profile. Between June and August, the nitrate concentrations are at their annual minima. This may be called a summer depression. In autumn of certain years, the nitrate concentrations show a slight increase, mainly in September.

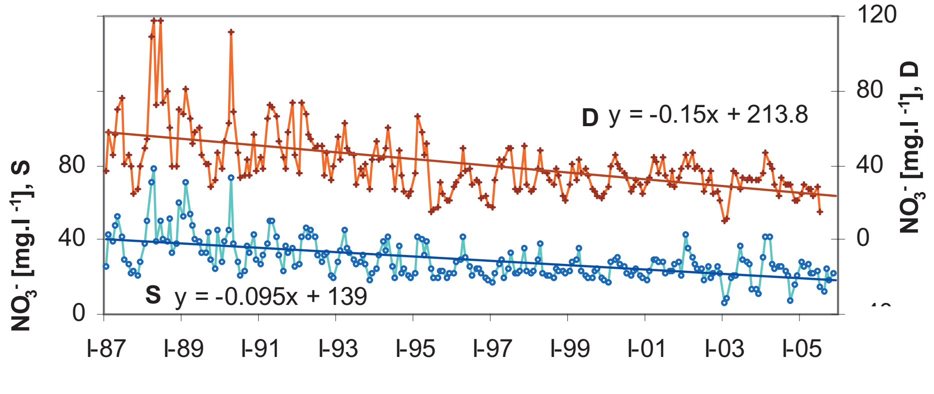

Fig. 3. Mean monthly nitrate concentrations in drainage runoff (D) and in stream runoff (S) of the microbasin Rybárik in the period 1987–2005

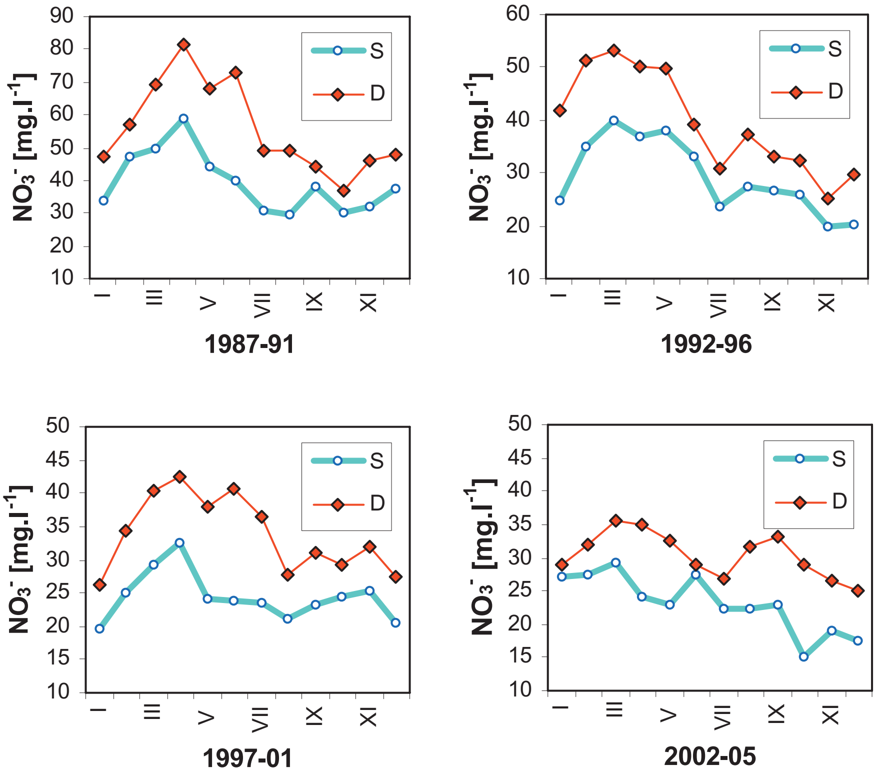

Fig. 4. Seasonal changes of nitrate concentrations in surface runoff (S) and drainage runoff (D) in 5-year periods of the years 1987- 2005

The annual nitrate losses from the agricultural microbasin

According to equation (1), the annual nitrate losses L_{run} [kg N.ha^{-1}a^{-1}] from the area of the agricultural microbasin Rybárik between 1987 and 2005 were calculated (Fig. 5):

$$L_{run} = \sum_{i=1}^{12} C_i . R_i k \qquad (1)$$

where C_i – monthly nitrate concentration in the month i [g.m^{-3}],
R_i – monthly runoff depth [mm], and k – constant (k = 0.01).

As Figure 5 shows, annual nitrate losses have a decreasing trend after 1989 with oscillations in certain years. These are caused by variations of annual precipitation and runoff, amounts of nitrogen fertilizers applied, the crops grown or combinations of these factors. For example, high annual precipitation sums in 1994 and 2002 caused high annual nitrate losses (88.8 and 105.4 kg N.ha^{-1}.a^{-1}, respectively). High amounts of nitrogen fertilizers applied to maize in 1987, 1988, 1992 and 1994 also resulted in high nitrate losses. The low nitrate loss in 2003 (25.6 kg N.ha^{-1}.a^{-1}) is due to a combination of low annual runoff and low amounts of nitrogen fertilizers.

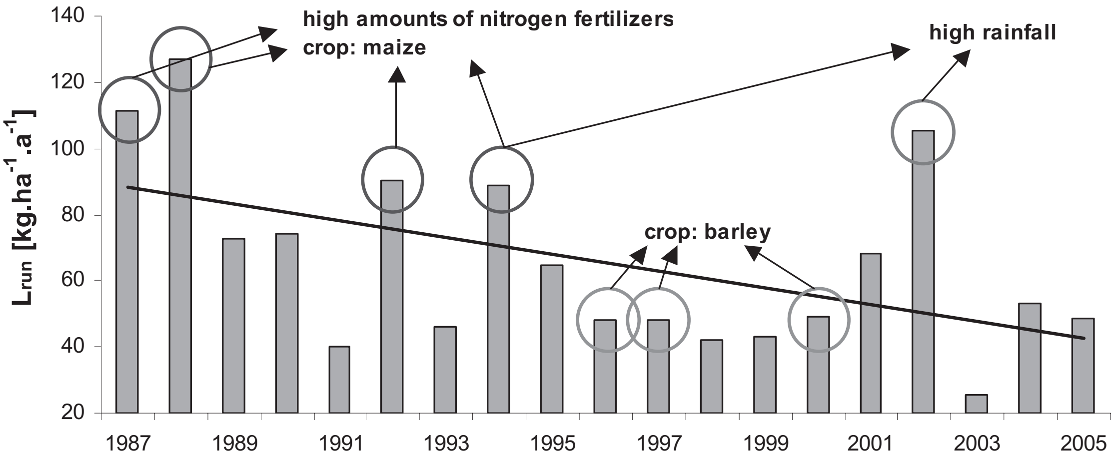

Fig. 5. Annual nitrate losses from the Rybárik microbasin between 1987–2005

Elaboration of experimental relationships

There are two basic types of experimental relationships to be used for estimating non-point source pollution loads (Jolánkai, 1992). We used relationships between the losses of a constituent measured at an observation point of a given recipient stream, and factors (parameters) affecting the changes of these measured losses values (such as flow or applied nitrogen fertilizers).

On Figure 6 there are displayed correlations between the annual nitrate losses and the runoff depth and between the annual nitrate losses and applied nitrogen fertilizers in the Rybárik microbasin. Interesting are years 1988 and 2003. Lower annual nitrate concentrations and nitrate losses in the year 2003 are result of combination of lower annual runoff depth and lower amounts of applied nitrogen fertilizers. Higher values in 1988 are probably result of higher amount of applied nitrogen fertilizers in the Rybárik basin.

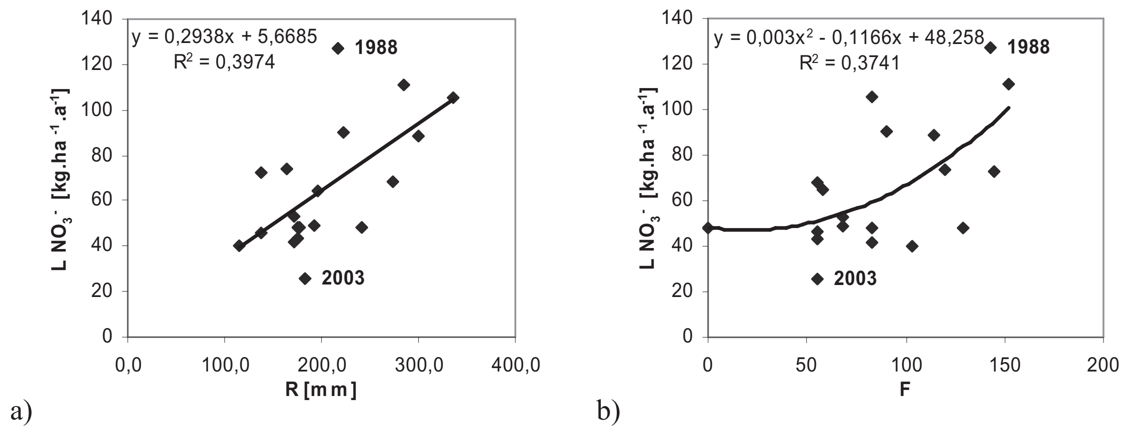

Fig. 6. Correlations between annual nitrate losses and a) the runoff depth, and b) the amount of applied nitrogen fertilizers in the Rybárik microbasin.

Following the empirical relationship (2) between annual nitrate losses, L_{mod} [kg N.ha^{-1}.a^{-1}], the annual runoff depth R_a [mm] and the annual amount of applied nitrogen fertilizers F_a [pure nitrogen in kg on 1 ha], were developed from a 19-year series in the Rybárik basin using the following multiple regression:

$$L_{mod} = 0.294\, R_a + 0.405\, F_a - 29.67, \qquad r^2 = 0.73. \qquad (2)$$

This empirical formula can be used for assessment of annual nitrate losses by surface runoff from small agricultural basins, using values of runoff depth and amounts of applied nitrogen fertilizers. Graphical comparison of the measured and modelled annual nitrate losses according to model (2) is made in Figure 7.

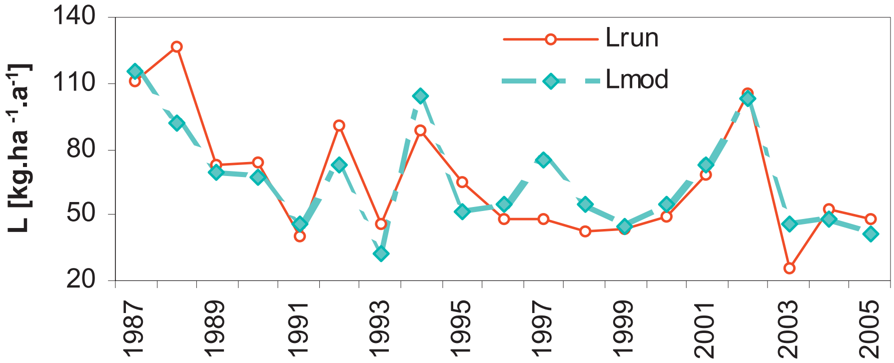

Fig. 7. Comparison of measured L_{run} and modeled L_{mod} (according to eq. (2)), the annual nitrate losses from the Rybárik microbasin

Summary

In this study, we used a 19-year series of runoff and water quality in the microbasin Rybárik. The data from the experimental agricultural basin Rybárik proved the influence of nutrient fertilization decrease on nitrate content in stream and drainage water. Despite the zero dose of fertilizers applied in 2005, the mean monthly concentrations of NO_3^- in stream water remained relatively high compared to the neighbouring forested microbasin Lesný (0.864 km^2, 90% forest). Mean annual NO_3^- concentrations in the forested microbasin Lesný are 10-times lower (under 2.5 $mg.l^{-1}$). This result shows that soil pollution by nitrates is lasting and leaching can take several years.

Based on measured data, an empirical relationship (2) was found describing the dependence of the annual nitrate losses on annual runoff depth and the annual amount of applied nitrogen fertilizers. The relationship can be used for assessment of the pollution losses in particular sub basins of the experimental basin of the Mošteník brook.

Acknowledgements

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